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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 34.

MILTON WHITNEY, Chief.

RECLAMATION OF ALKALI SOILS.

BY

CLARENCE W. DORSEY.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1906.

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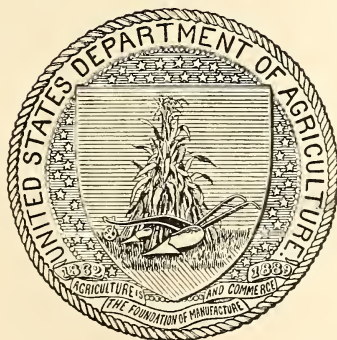
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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., March 23, 1906.

SIR: I have the honor to transmit herewith, and to recommend for publication as Bulletin No. 34, the manuscript of an article on Reclamation of Alkali Soils, prepared by Mr. Clarence W. Dorsey, of this Bureau. The preparation of this paper was suggested by the increasing interest taken in the alkali reclamation experiments now in progress in several parts of the arid West under the direction of this Bureau, and is designed to meet the constant inquiries for full information on this all-important Western problem.

Very respectfully,

MILTON WHITNEY,
Chief of Bureau.

HON. JAMES WILSON,
Secretary of Agriculture.

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RECLAMATION OF ALKALI SOILS.

INTRODUCTION.

A problem of paramount interest in many irrigated districts in the arid States is the successful treatment of alkali soil. With the practice and extension of irrigation, damage has been caused by the rise and spread of alkali. Few districts are entirely free from this damage, while in many the trouble increases from year to year. It is estimated that in about 10 per cent of the areas in the irrigated districts surveyed by the Bureau of Soils alkali is more or less a serious menace to agriculture. In certain localities successful farms of a few years ago are now abandoned, flourishing fields have been transformed into barren alkali flats, and land values have greatly depreciated, all on account of alkali. In discussing the subject many questions naturally arise: What is alkali; how has it accumulated in the soils; can its accumulation be prevented; having excessive quantities in the soil, can it be removed and the soil restored to its original fertile condition?

DEFINITION OF ALKALI.

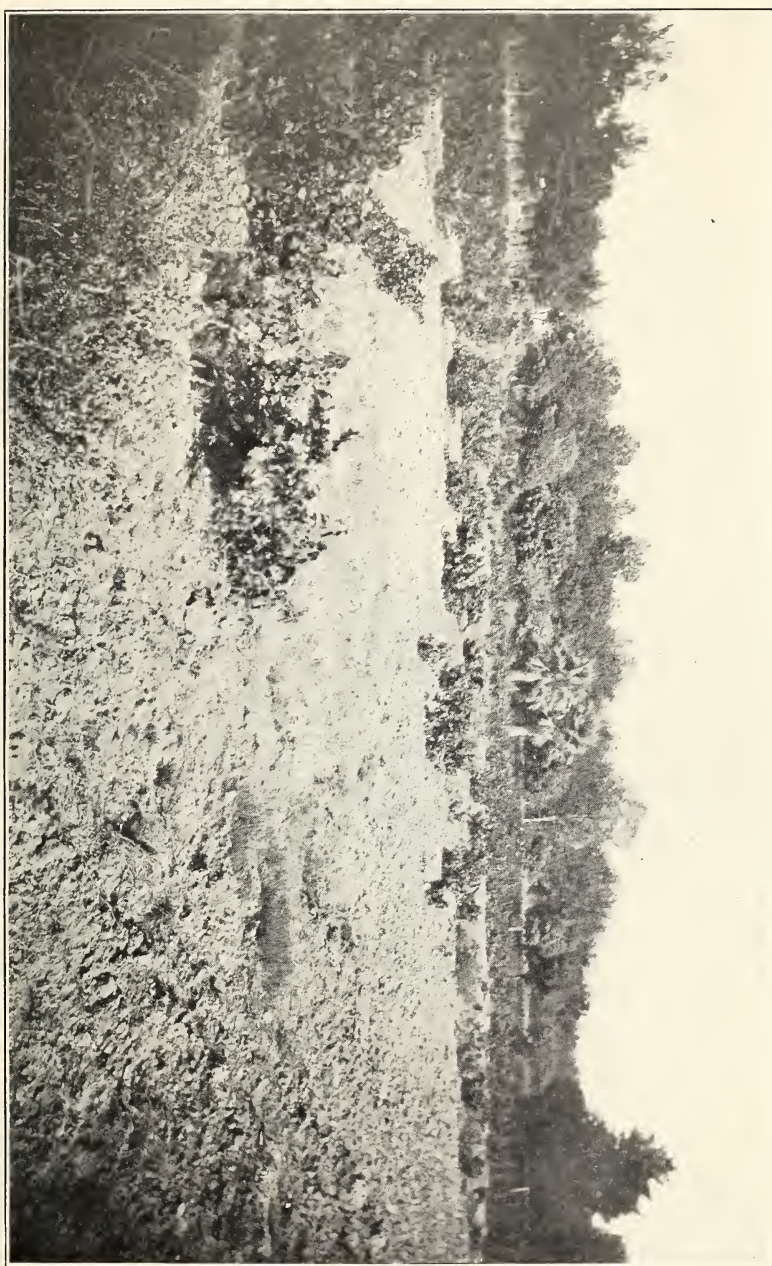
The term "alkali," as commonly used in arid and semiarid regions, refers to accumulations of water-soluble mineral salts. The principal substances composing alkali consist of chlorides, sulphates, and carbonates of sodium, magnesium, and calcium, or a mixture of two or more of these salts. Other substances may be found, but they are relatively unimportant. Generally speaking, alkali consists of three principal ingredients—sodium chloride or common salt, sodium sulphate or Glauber's salt, and sodium carbonate or sal soda. Alkali is commonly spoken of as white alkali and black alkali, depending on the appearance of the incrustations caused by excessive accumulation on the surface. Usually when large quantities of sodium sulphate or sodium chloride accumulate on the surface its presence is marked by a white incrustation, hence the term in common use—white alkali. Since sodium carbonate, when present in considerable quantities, corrodes the vegetable matter of the soil, forming a brown or dark stain, it is called black alkali. As calcium chloride, a comparatively harmless salt, may likewise impart a dark stain to the soil, it is evident that this classification is not altogether satisfactory, though it will probably always continue in local use.

ORIGIN OF ALKALI.

The soils of arid regions, as compared with those found in humid regions, are by far the richer in water-soluble mineral salts. During the processes of soil formation many changes take place before huge boulders and rock masses are converted into soils capable of supporting vegetation. Freezing and thawing, and the action of the winds, rains, water, and ice, in the course of time reduce rocks to the more finely divided particles that finally constitute a soil in the true sense of the word. The minerals composing the original rock are broken apart and the chemical changes incidental to rock weathering set free quantities of soluble salts. Whether these salts remain in the soil depends on the amount and distribution of the rainfall of the region. In countries having an abundant rainfall the greater part of these soluble mineral salts is leached away, but in regions of limited rainfall most of these salts remain in the soil. Much of this soluble material constitutes the alkali of arid regions, and so in many places we can trace the origin of the alkali directly to the rocks which have weathered into soils. As a general rule, we find that in regions having a rainfall of less than 20 inches more or less alkali is present, while with a rainfall greater than 20 inches the tendency for such accumulation is materially lessened. In some places the origin of the alkali is due to the evaporation of bodies of sea water that have been cut off by various causes. East of the ninety-ninth meridian alkali is frequently found, but the rainfall is usually so great that the alkali question does not assume the importance it has in States farther west.

ACCUMULATION OF ALKALI.

Since the salts composing alkali are readily soluble in water, it is evident that, while they will remain stationary in a dry soil, when water is added they will be dissolved and move within the soil in whatever direction the water moves. Farmers living in an arid region are perfectly familiar with this phenomenon. They have noticed that places heavily incrustated with alkali show no such crusts after heavy rains or the application of irrigation water. The alkali dissolves in the water and with it soaks into the soil, but as the soil dries out it again makes its appearance on the surface. This is because the greater part of the water added by the rains or irrigation returns through evaporation to the surface, and when it evaporates all of the dissolved salts are again deposited on the surface. Many farmers in a new irrigation district have found to their sorrow that after a few years of irrigation alkali has appeared where they little imagined it was present. In such cases the appearance of alkali is due to the fact that the irrigation waters have penetrated to the deep subsoil, dissolving the stores of soluble salt held there. Subsequent



FIRST APPEARANCE OF ALKALI IN A VINEYARD NEAR FRESNO, CAL.

The former uniform growth of vines is being destroyed as the alkali conditions grow worse from year to year.

evaporation of much of this water at the surface deposits the salts dissolved from the entire column of soil. If sufficient water were added not only to start a downward movement of the salts, but also to leach them away into the country drainage, the soil would then be entirely free from such accumulations.

In most irrigated districts just such changes have been brought about, and as a matter of fact most of the accumulations of alkali in cultivated fields are due to the local concentration caused by the irrigation water carrying the soluble alkali from one part of a district to another. Usually the alkali is removed from higher-lying to lower-lying areas where, on account of the low position, there is a tendency for the drainage waters to collect. In such areas the underlying subsoil is filled with water until capillary connection between the subsoil and the surface is established. By continued evaporation of this capillary water the soluble salts are deposited at or near the surface. In many areas such accumulations would never have taken place had precautions been taken to provide the necessary drainage at the time the irrigation canals were built. Unfortunately in most irrigated districts no such precautions were taken, as at that time the country was suffering from a lack of water and no thought was given to the future drainage of the district. Irrigation canals and ditches are made to furnish the water needed to grow crops. At this time the ground water is usually many feet below the surface. Alkali may be present in small local spots, but usually such places are small and considered unimportant. As irrigation is continued, water gradually accumulates in the lower places, and these places gradually increase in size while accumulations of alkali also begin to appear. Even then no provisions are made for drainage and the damage resulting from the rise of the ground water and alkali accumulations continues to increase until in many districts the choicest farm lands are thrown out of cultivation.

EFFECT OF ALKALI ON CROPS.

When any considerable quantity of alkali is present in soils it exerts a toxic or poisonous influence on the crops. (See Pl. I.) Not all plants are affected alike by alkali, for it is well known that some can withstand quantities of alkali that would be fatal to others, nor are the various kinds of alkali equally injurious to the different crops.

Certain plants, on account of their immunity to relatively high concentrations of alkali, have come to be known as resistant, while others more easily injured are classed as sensitive. Among the resistant cultivated plants are certain varieties of barley, sorghum, and sugar beets, while corn and wheat furnish examples of more sensitive crops. Alfalfa in its younger stages is sensitive to alkali, but when once well established becomes quite resistant. Certain weeds and native plants

(such as salt grass, greasewood, and the saltbushes) indicate the presence of alkali in the soil, even though no traces may appear on the surface. Sage brush and rabbit bush are generally supposed to denote alkali-free soils. Frequently the native vegetation is used as a guide in selecting soils in new districts and is generally to be relied upon.

Of the different classes of alkali, sodium carbonate, or black alkali, is considered the most injurious. Laboratory experiments have shown that magnesium chloride and sulphate are equally if not more injurious than sodium carbonate. After these salts comes sodium chloride (ordinary salt), and last sodium sulphate. When present in soils to the exclusion of other salts, 0.05 per cent of sodium carbonate represents about the upper limit of concentration for common crops. One-half of 1 per cent of sodium chloride is commonly regarded as the endurance limit of crops, and 1 per cent of sodium sulphate. Sodium sulphate, then, is the least injurious and sodium carbonate the most injurious of the salts usually constituting the greater part of alkali under ordinary field conditions, while sodium chloride occupies a middle position. As the alkali conditions in a soil may change from day to day, depending on the moisture present in the soil, it is exceedingly difficult to determine the exact amounts of total salts that any given crop can withstand. Again, since there is generally an admixture of the various salts present in the soil, we seldom have an opportunity to study the effect of any single salt on crop growth. Enough is known to establish the approximate accuracy of the effects of the three salts as given above. The fact that a plant is growing in soil heavily incrustated with alkali does not necessarily mean that the plant at any time came in contact with so much alkali. Rains or irrigation may leach the alkali from the upper few inches of soil, thus enabling the planted seed to germinate freely. As the roots develop and penetrate deeper for moisture and food supply, the alkali may slowly accumulate at the surface in such a manner that the plant is not affected.

The first apparent effect of alkali is in retarding germination. Usually the vitality of the seed is not affected, and if water subsequently leaches the alkali below the seeds will then germinate. Of course, if the alkali content remains unchanged no germination will take place in soils carrying considerable alkali. (See Pl. II.) In case much black alkali is present the effects are very pronounced. This salt has the power actually to decompose seeds as well as growing plants and has been known to destroy completely the hard outer bark of mature trees.

METHODS OF PREVENTING ALKALI ACCUMULATIONS.

In many districts where alkali is rapidly spreading, the farmer is chiefly concerned with any course of treatment that will prevent excessive quantities from accumulating in his soil. Slight amounts of

alkali do not harm crops, but probably exert a beneficial action upon them, so that the farmer's first interest is to check accumulation beyond the limit of safety. Economy in the use of irrigation water is the first step to be taken. By using as little water as possible the farmer postpones, perhaps indefinitely, the time when the water table shall rise sufficiently high to cause surface accumulations of alkali. With a constantly rising water table, not only is the accumulation of injurious salts accelerated, but the deep-rooted crops and orchard trees are injured or killed by the excess of water. Many fine fields of alfalfa have been entirely ruined by using excessive quantities of water. The ground water, already dangerously near the surface, is further raised, capillary connection is established, and with the evaporation of at least a portion of this water conditions are made extremely favorable for the final abandonment of the field as a result of excessive alkali accumulation. Supplying to the crops only sufficient water for their growth is one method, then, of actually preventing accumulations of alkali beyond the danger point.

The above remarks apply where the soil is reasonably free from alkali and the irrigation water is of good quality, but where there is already a large accumulation of salts economy in the use of irrigation water is one of the worst methods. When the soil contains a relatively large amount of salt and but little water containing much salt is frequently applied, the ordinary evaporation will increase the salt content of the soil to such an extent that crops can no longer survive, whereas if adequate drainage is provided and a large amount of water is used the excess of salt resulting from the evaporation of previous applications of water may be removed and the soil moisture be maintained at nearly the same concentration as the water supply.

As bearing upon this subject it is important to refer to the practice of Arabs in the Desert of Sahara in eastern Algeria. Thomas H. Means, formerly of this Bureau, visited that country in 1902. He found, in addition to the cultivation of the resistant date palm, that large quantities of deciduous fruits, garden vegetables, and alfalfa are produced. Many of the crops grown are quite sensitive to alkali, and yet they were being irrigated with water containing in some instances as much as 800 parts of soluble salts to 100,000 parts of water. Sometimes as high as 50 per cent or 400 parts of the salts found in the irrigation water were sodium chloride. This is greatly in excess of the limit of concentration for irrigation water, which by some authorities has been placed at from 200 to 300 parts per 100,000.

The manner in which irrigation water containing such large quantities of saline matter is used is described as follows by Means in Circular No. 10 of this Bureau:

The prerequisite to the use of water of high salt content in irrigation is the knowledge that the methods employed are opposed to the teachings of most American writers on the

subject. Those who place the low limit of safety for alkaline irrigation waters have taught that where water was badly alkaline irrigation should be sparing. They have not insisted on thorough drainage, and they have warned irrigators against too frequent irrigation. With such practices the limit of concentration which they set is probably high enough, and even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged.

The methods in the cases are quite different. The Arab gardens are divided into small plots about 20 feet square, between which run drainage ditches dug to a depth of about 3 feet. The soils being very light and sandy, this ditching at short intervals insures the most rapid and thorough drainage. Irrigation is by the check method, and application is made at least once a week, though often two wettings a week are deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of the water downward is maintained. There is little opportunity for the soil water to become more concentrated than the water as applied, and the interval between irrigations being so short but little accumulation of salt from evaporation at the surface takes place. What concentration or accumulation does occur is quickly corrected by the succeeding irrigation.

The natives not only have the question of very saline irrigation waters to contend with, but the soils originally are often very alkaline. In three years they reclaim land too salty to grow the minor crops, using the saline water for that purpose, following the same plan of drainage and weekly irrigation as where crops are growing.

Surface irrigation as opposed to subirrigation is another important question to be considered on soils where there is any liability to alkali accumulation. By applying all water to the surface whatever salts may have accumulated there are dissolved and carried downward into the soil to the depth penetrated by the irrigation water. This insures a downward movement of the salts each time the field is irrigated. With subirrigation the water is supplied at some point below the surface, where it dissolves the salts contained in the soil with which it comes in contact. Since some of this water eventually reaches the surface by evaporation, just so much salt will be deposited there as is contained in the subirrigation water brought up by capillary action. Subsequent applications of water by subirrigation by dissolving more salt tend to increase still further the quantity of salts deposited on the surface.

By many it will be regarded that the evil effects of subirrigation have been greatly overestimated; that the good effects more than counterbalance possible injury which may follow. It is true that subirrigation in many cases is practiced where sufficient water is not always available for surface irrigation, and that the greatest economy in the use of water is possible by this method. But even these objections do not disprove the statement that the invariable result of subirrigation is to eventually deposit at or near the surface the greater part of the salts contained within the zone of soil moistened by the subirrigation water. In many cases years have elapsed before sufficient alkali has accumulated within the upper few inches of soil to injure crops, but more often the damage ensues within a few years after subirrigation is practiced. Perhaps one of the most prominent instances of alkali accumulations caused by subirrigation is in portions

of the San Joaquin Valley, California. Here large areas of once fertile soil have been ruined by the rise of black alkali, largely as the result of the practice of subirrigation and the consequent fluctuating of the water table. The ground water rises rapidly after water is turned into the canals each spring. The loss of water from the canals by seepage is enormous on account of the sandy soils through which they pass. In spite of the frequent cultivation given the soils some water is evaporated at the surface and its dissolved salts deposited there. Applying water upon the surface early in the spring, when the water table is still several feet deep, would insure a downward movement of the alkali accumulated near the surface during the previous year. Then by reducing surface evaporation as far as possible by cultivation the salts might be held in the lower depths of soil.

Even irrigating by furrows is one form of subirrigation that allows whatever salts are contained in the soil to be deposited at the tops of the slight ridge caused by the furrow. In case furrow irrigation is the best, and it is often the only method available, occasional smoothing of the surface and flooding the entire field greatly helps to check the accumulations caused by continued furrow irrigation.

In this connection it seems advisable to insist on thorough smoothing or leveling of the surface before irrigation. In too many cases not enough care is given to the initial preparation of the land; that is, before any cultivation is begun. The farmer, anxious to get returns on new land with the least expenditure of time and labor, often neglects thoroughly to level his land at the outset. He realizes that there are still high spots in the field that water will not reach, but hopes eventually to complete the leveling, in the meantime relying on the lateral movement of the water to moisten the higher portions of the field. As a result, when the lower, more level parts of the field are irrigated, the water creeping up to the high spots evaporates there, and in the course of time deposits excessive quantities of alkali. Frequently from these high spots the alkali slowly spreads until it becomes a serious menace to the entire field. All this could have been avoided by thoroughly leveling the field in the beginning, so as to insure an even flow of water over the entire field.

The next important consideration in preventing excessive alkali accumulations at or near the surface is to restrict as far as possible surface evaporation. With all irrigation water applied to a carefully leveled surface it is evident that the salts will be leached downward, and can only return to the surface upon evaporation of the soil moisture. Any method of treatment, then, that prevents evaporation necessarily retards the rise of the alkali. If evaporation were entirely eliminated there could be no surface accumulation of alkali. Unfortunately, however, we can not entirely prevent evaporation, although we can in a measure control it. Cultivation, mulching with straw or leaves, or

shading the surface by crops tend to restrict surface evaporation. Frequent shallow cultivation by keeping the upper few inches of soil in a loose condition breaks the ascending column of capillary water, and thereby reduces the quantity of water that can reach the surface. Scattering leaves or straw protects the surface from the direct rays of the sun and also reduces evaporation. In many cases retarding evaporation by mulching the surface in this manner is hardly practicable on account of the cost, although it is quite effective. Frequently in the spring, after the winter rains have washed the alkali a short distance below the surface, it is possible to secure a stand of rapid growing crops that will furnish a dense shade by the time hot weather comes on. Many cases are on record where land containing appreciable quantities of alkali have been utilized in this manner. The shade furnished by the crop checks excessive evaporation, while frequent surface irrigations still further operate to drive the alkali into the lower depths of soil. While there are undoubtedly many cases where excessive quantities of salts will accumulate in the soil in spite of the utmost precautions, it is believed that much good can be accomplished by paying attention to some of the above considerations.

TREATMENT OF ALKALI SOILS.

We must now consider what use can be made of soils containing excessive quantities of alkali. Can their reclamation be accomplished, and if reclaimed can they be successfully farmed? Is it really necessary to reclaim them? Can not some revenue be derived from them in their present condition? For convenience the treatment of alkali soils may be discussed under the following heads: (a) Cultivation of alkali-resistant crops; (b) use of chemical antidotes; (c) removing alkali from the soil by various methods.

CULTIVATION OF ALKALI-RESISTANT CROPS.

The method of attacking the problem by cultivation consists of utilizing alkali soils by growing crops that are capable of enduring large quantities of salts. This would be the simplest method, provided crops could be found that would grow on all classes of alkali soils. Unfortunately, large areas of land contain so much alkali that not even the most resistant weeds or bushes can live. On such lands it is hopeless to attempt the cultivation of any crop until a portion of the alkali is removed. Certain saltbushes successfully withstand large quantities of alkali, and chemical examination of some varieties proves their value as forage crops. Their cultivation has been widely advocated by many writers on the subject. Saltbushes from Australia were introduced into California more than twenty years ago, but the most valuable species was not brought in until many years later. This is now commonly known as the Australian saltbush

(*Atriplex semibaccata*), and, on account of its rank growth and ability to resist drought as well as alkali, has been somewhat extensively cultivated in California, Arizona, and New Mexico. It may be used for pasturage or cut and cured as hay, yields of several tons per acre being not at all unusual. While this species does not thrive in the colder climate of the more northern States, native species do exist that give promise of success if cultivated. Speaking of the saltbushes of economic value in Wyoming, Nelson^a says:

Only the herbaceous species or those not woody are suitable for cultivation. Such are Nuttall's saltbush, Nelson's saltbush, and three annual species. Their cultivation would not be profitable on land where it is possible to grow forage plants which make a ranker growth and are more acceptable as feed to stock. Only on alkali lands unsuitable for other crops is it advisable to plant the saltbushes, and good yields will not be realized except on lands which are tolerably moist and which have been put in good condition of tilth.

While the cultivation of saltbushes has not perhaps been practiced long enough to make definite statements as to the future, sufficient trials have been made to prove that under certain conditions some revenue may be derived from land that would otherwise be non-productive. By many it has been urged that the growing of such plants, which assimilate considerable quantities of salts, really becomes a means of freeing the soil of alkali. While it is true that such plants do take from the soil considerable alkali, the quantity absorbed by the plant as compared with the quantity remaining in the soil is very slight, so that years would be required to effect complete reclamation in case no other factors entered into the problem. This method, however, merely removes some alkali from the surface soil, while the rise of additional quantities from the subsoil is not prevented. On lands which will admit of other more profitable crops to be grown, sorghum ranks high as an alkali-resistant crop. At the Tulare substation the California experiment station reports sorghum growing luxuriantly in soils having a large amount of alkali, the surface often having a very dark incrustation from the black alkali. In the surface foot of soil chemical analysis revealed 0.872 per cent of total salts, a little more than half this quantity in the second foot, and slightly less quantities in the third and the fourth foot. The predominating salt was sulphate. From these results sorghum would seem to have a high tolerance for alkali salts and may be expected to grow where many other crops fail. Some varieties of barley and oats, as well as sugar beets, are also known as resistant crops. With these crops, however, when the quantity of total salts is as great as 0.60 per cent, difficulty is generally experienced in securing a stand. From these considerations it appears that for soils containing large quantities of alkali the crops capable of profitable cultivation are few in number at the present time, and

^a Native and Introduced Salt Bushes, by Elias Nelson. Bul. No. 63, Wyoming Agr. Expt. Sta., 1904.

that unless varieties are found that will withstand more alkali the use of alkali lands for crop production without reclamation is extremely circumscribed.

USE OF CHEMICAL ANTIDOTES TO RECLAIM ALKALI SOILS.

It has long been known that gypsum (calcium sulphate) exerts a beneficial action on soils containing black alkali, or sodium carbonate. It has not been found possible so far to add any substance that will neutralize white alkali, so the treatment of black-alkali soils alone need be considered. The application of gypsum to soil containing black alkali results in chemically changing the sodium carbonate or black alkali to sodium sulphate or white alkali. As compared with the carbonate the sulphate is quite harmless unless accumulated in much larger quantities. In addition to the chemical change attendant upon the use of gypsum the tilth of the soil is much improved. As a corrective for black-alkali soils, gypsum has been extensively used in California. In many cases when applied with sufficient water, it has been found possible to grow crops on land where previous attempts had resulted in failure. At the Tulare substation the California experiment station experimented for many years with the use of gypsum. Land was reclaimed to such an extent that crops could be grown, but in some places alkali came in from fields adjoining the experimental plot and more gypsum had to be applied.

With only small quantities of black alkali, and with the absence of other salts, beneficial results should follow the use of gypsum. In such cases the quantity of white alkali resulting from the chemically changed carbonate would be so small that it would not prevent the growth of crops. With a well-drained soil and conditions not favorable for a further increase of alkali in the soil the effects of this treatment should be permanent. On the other hand, if there is already considerable white as well as black alkali in the soil, the use of gypsum becomes more doubtful. With other forms of alkali present, the white alkali formed by the gypsum added to that already in the soil may often be sufficient to prevent crop growth. Again, it should be pointed out that while the black alkali may be changed to the less injurious sodium sulphate, conditions may again become favorable for the formation of more black alkali, necessitating the use of gypsum a second time. Moreover, there is the objection that gypsum does not remove the cause of the accumulation. Even considering these objections, there are undoubtedly many localities where the use of gypsum is to be recommended for soils containing small quantities of sodium carbonate.



ALKALI FLAT IN SALT LAKE VALLEY, UTAH.

The soil contains so much alkali that only the most resistant plants can live. No useful crops can be grown on such land.

METHODS OF FREEING SOILS FROM ALKALI.

Any method that will remove accumulations of alkali from soils, whether these accumulations were formed by natural causes prior to irrigation or are the result of overirrigation on undrained soils, should receive careful consideration. Evidently the question of cost is of primary importance, since it will not pay to expend a greater sum of money to free the soil from alkali than the land is worth when reclaimed. Another vital point is whether the reclamation is permanent, for little real progress is made if land freed from alkali one year will accumulate sufficient alkali to prevent crop growth the following season. Some of the methods recommended and used more or less in different sections are: Scraping the surface; flushing alkali lands with water, then draining off the water; copious irrigation or flooding; flooding after the land has been artificially drained. Under favorable conditions any of these methods may be used and the soil put in condition for the cultivation of any crop suited to the soil and climatic conditions. So many factors enter into the successful treatment of alkali soil that every field, often every part of the field, should be studied before deciding on the course of action that should be followed. Because a certain method has reclaimed land in any particular area does not argue that it can be safely used in other places unless the same conditions prevail. Even then it may seem advisable to attack the problem in an altogether different manner. The causes of the alkali accumulation should be studied, also the amount and character of alkali. The vertical distribution of the alkali in the soil is important, and the character of the soil, whether it is sandy or clayey, impervious or readily permits water to move through it. Lastly, the depth to standing water should be carefully noted, as well as the position of the field or farm with reference to adjacent lands. It is only after due consideration has been given to all of these questions that we are in a position to recommend specific treatment for each individual tract of land. We may now briefly discuss the different methods that have been outlined above to determine under what conditions they are to be advised.

SCRAPING THE SURFACE.

At the close of a dry season much alkali can be removed by merely scraping lightly the surface of the soil. In case the greater part of the alkali is concentrated in the upper few inches of soil the quantity may be so reduced by scraping that crops can be started the following year. By shading the surface the growing crop restricts evaporation of the soil moisture, while subsequent surface irrigation tends to drive the remaining alkali downward, where it can do little if any harm. The success of this method of reclamation also requires that the water

table be several feet from the surface. With these conditions this treatment may be the means of permanently freeing the soil of slight quantities of alkali and rendering it suitable for ordinary farm crops. While such a method is not generally to be recommended, since it does not remove the cause of the accumulation, it is apparent that under certain conditions it may be one method of eventually reclaiming alkali land at a very slight outlay of time and labor. Few if any instances of the successful use of this method have ever been recorded.

FLUSHING THE SURFACE.

Frequently an attempt is made to free the soil from alkali by turning water across a field, holding it on the land for a short time, and then draining it off. The principle involved is to allow the water to dissolve the salts in the upper part of the soil and on the surface, and then by immediately draining it off to carry the dissolved salts away. On sandy or porous soils with a shallow water table this method is very objectionable and increases the evil for which it is supposed to be a remedy. With the application of water to sandy soils the salts would at once be dissolved, but much of the water would sink into the porous soils and further raise the ground water, already so high that it is a fruitful source of alkali accumulation. The portion of water drawn off would undoubtedly carry some alkali, but this advantage would be negligible as compared with the resulting disadvantages. Yet under just such conditions flushing the surface is being resorted to in many districts by farmers who apparently do not realize the error they are committing.

The conditions favorable for this treatment are rather heavy or somewhat impervious soils, with the alkali largely concentrated at the surface and the water table several feet below. With these conditions the question of raising the ground water by the portion of water soaking into the impervious soil is relatively unimportant. The alkali, largely a surface deposit, will be dissolved and the greater part of the water will be drawn off with its dissolved salts. A few flushings may so reduce the quantity of alkali that crops can be started, and with the precautions of surface irrigation and restricting evaporation by shading the surface or by cultivation the land may be made productive. This method, although of somewhat limited application, may result in the permanent reclamation of alkali land.

FLOODING WITHOUT ARTIFICIAL DRAINAGE.

Certain definite conditions are necessary before this method can be recommended. The most essential points are that the soil be naturally well drained and the water table several feet below the surface. Under these circumstances the soil may be freed from

even excessive quantities of alkali. After leveling the field sufficient water is added to cover the surface to a depth of several inches. By means of dikes or levees the water is held on the land and must of necessity soak through the soil, carrying with it the more readily dissolved salts. Repeated flooding finally leaches away the greater part of the alkali and enables the land to be cultivated. By care in handling such reclaimed land the chances for a second accumulation of salts are slight, provided that the ground water be kept sufficiently far below the surface. As much of the soil in the arid west is of a sandy nature, implying good drainage within the soil, the question remains just how deep must the ground water be to make reclamation by this method safe. This is a point that should be carefully considered, as well as the position of the field with reference to adjacent lands. Conditions may be such that with the ground water 3 feet or less below the surface the field may be entirely freed from alkali by this method. The alkali is leached below the surface and carried away with the country drainage where it works no injury to the soil being treated. With the ground water at this depth (3 feet), in case the reclamation of a large tract of land is attempted, the ground water would probably be raised above the danger point. So that while it might be possible to reclaim a tract of a few acres with a high water table, it would be a mistake to attempt the reclamation of a larger tract. Many cases have been observed where small tracts of alkali land have been completely reclaimed by flooding even where the water table was comparatively high. Likewise it should be mentioned that many failures have also been made by attempting reclamation under almost similar conditions. With the ground water 4 or 5 feet or more below the surface such attempts at reclamation are much more likely to succeed. The deeper the ground water the more readily will the water used in flooding leach the soluble salts into the deep subsoil, thereby diminishing the probability of their return to the surface. The success or failure of this method depends a great deal on choosing just the right time to start the crop. With the surface soil freed from alkali even to the depth of a few inches a piece of land may be entirely reclaimed. This enables the crop to start, and its growth effectually checks evaporation at the surface, while subsequent irrigation tends to reduce still further the alkali content of the soil. (See Pl. III.) Sorghum has frequently been recommended as a suitable crop to plant on land where the quantity of alkali is still considerable. This crop, as has been pointed out, is able to withstand not a little alkali, and at the same time admits of copious irrigation.

FLOODING COMBINED WITH ARTIFICIAL DRAINAGE.

When the ground water is high and cultivation is impossible as a result of seepage water and alkali, drainage must be resorted to before any real progress can be made. Even though the water table fluctuates greatly during the year recourse must be had to drainage, provided that at any time the water rises high enough to damage the deeper growth of crops or trees. A fluctuating water table, by submerging even for a few months the new feeding roots, may inflict as much injury as excess of alkali or a permanent high water table. Many cases have been observed where the loss of deep-rooted crops, orchards, and vineyards has been attributed to alkali when the sole cause of trouble was the extraordinary height of ground water at certain periods of the year. Some method of lowering the ground water at such time is as necessary as when the water table remains high throughout the year.

The method available for lowering a high water table or maintaining a fluctuating water table at a certain depth is some system of drains operated either by gravity or by pumping plants. The relative merits of the two systems must be decided after a careful consideration of the object to be accomplished. When the purpose to be gained is merely freeing an area of an excess of seepage water, thereby furnishing the initial step in the ultimate reclamation of the land, a system of gravity drains may be all that is needed. If, on the other hand, it is proposed not only to lower the water table, but also to develop additional water for irrigation, pumping plants may be necessary. In either case the question is purely an engineering problem and a competent engineer should be consulted before attempting operations on a large scale.

On small tracts of land with the ground water dangerously high and excessive quantities of alkali a system of gravity drains is perhaps the simplest method of attacking the problem. With such a drainage system in good working order the water table is permanently lowered to the depth of the drains. A ready outlet is provided through which not only seepage water from higher lands but the excess of water used in flooding or irrigation may carry away the harmful accumulations of salts leached out of the soil. Repeated flooding should eventually entirely free the soil from alkali, while the danger of future accumulations is greatly lessened by careful irrigation and precautions to prevent excessive surface evaporation. The principle of this method of reclaiming alkali land is exceedingly simple, but there are difficulties in carrying it out and many factors should be considered before attempting reclamation in any district. Inasmuch as the Bureau of Soils has been carrying on demonstration experiments by this method it seems advisable to describe somewhat briefly the progress of the work and results obtained at each reclamation tract.

RECLAMATION EXPERIMENTS OF THE BUREAU OF SOILS.

In 1899 the Bureau of Soils undertook the classification and mapping of soils in the United States. Methods for rapidly determining the quantity and character of alkali were devised and these methods used in the field. The origin and distribution of the alkali were studied, as well as the various quantities of the different kinds of alkali sufficient to prevent the successful growth of crops cultivated in each area. Carefully prepared maps were also made showing the exact amount and distribution of alkali in each area. In addition recommendations for handling such lands were made in the reports describing the results of the work. It was emphasized that by providing suitable drainage the soluble alkali could be leached from the soil by repeated irrigation and the soil restored to its original fertile condition. As years passed by with no effort on the part of those interested to undertake such methods of relief the Bureau became convinced of the advisability of taking up reclamation work as the best means to prove the force of its recommendations. Accordingly a number of locations were selected in which such demonstration work should be undertaken.

In the summer of 1902 work was begun near Salt Lake City, Utah; in the winter of 1902 a second tract was selected at Fresno, Cal.; in 1903 a third tract was chosen at North Yakima, Wash. During 1904 reclamation experiments were started at Tempe, Ariz., and at Billings, Mont. At each of these stations the soil conditions and the character of the alkali differ. At each tract selected a drainage system of ordinary draintile was installed to a depth of 3 or 4 feet, the land leveled and divided into checks or plats by levees, so that it could be flooded, and ample provision was made for the removal of the drainage water. Careful tests were made to determine the amount and character of alkali present and arrangements were made to measure the water applied in flooding, as well as the quantity carried off by the drainage system. Tests were also made to determine the amount of alkali removed by the drainage water.

At Salt Lake City, Utah, a tract of 40 acres was selected and the work was carried on in cooperation with the Utah experiment station. The tract is situated about 4 miles west of the city and in its original condition supported only a sparse growth of the alkali-resistant greasewood and salt grass. Nearly the whole 40 acres was heavily incrustated with alkali deposits and the appearance of the tract was about as unpromising as one could well imagine. No attempt had ever been made to cultivate the land, but a railroad embankment crossed it and streets had been graded upon it. The soil consists of a heavy silty loam with a clay subsoil. Tests showed the quantity of alkali to a depth of 4 feet to average from $2\frac{1}{2}$ to 5 per cent, mainly

sodium chloride or common salt, or more than five times as much as ordinary crops will tolerate.

The drainage system was installed late in the summer of 1902. This consisted of lines of drintile 150 feet apart at an average depth of 4 feet. During 1903 systematic flooding was carried on from May to October. Tests at the close of the season showed that by far the greater part of the alkali had been leached from the soil. In the spring of 1904 the entire 40 acres was planted to wheat, oats, and barley. On account of late seeding the stand was not the most promising, but was ample to show that the upper foot or more of soil had been practically reclaimed. Flooding was carried on for about six weeks in 1904. Crop tests in 1905 gave better results. At present (March, 1906) 13 acres are in alfalfa with a good stand; 4 acres are in winter wheat, while alfalfa and other crops will be planted on the remainder of the tract.

A second tract of 20 acres was selected 4 miles south of Fresno, Cal., and a drainage system installed during the winter of 1902. This tract of land was at one time considered some of the finest fruit and vineyard land in the Fresno district. At the time irrigation was first commenced in this region the water table was in the neighborhood of 80 feet below the surface. By using excessive amounts of water and by the enormous loss from the canals running through the sandy soils of the country the entire region became filled with seepage water until at the present time the water table in some sections rises to within 1 foot of the surface. Attendant upon the rise of the ground water came the bad effects due to the accumulation of alkali, and for miles in this part of the Fresno district former fine vineyards and orchards are now abandoned or valued only for their scanty pasturage. In the Fresno tract no outlet was available for the drainage water, except by installing a water-wheel pump upon one of the irrigating canals and lifting the drainage water from a deep sump dug for this purpose. The soil of the tract is known as "white ash land" and is a fine sandy loam which contains considerable volcanic ash. The alkali on this tract consisted largely of sodium carbonate, or the dreaded "black alkali."

Flooding was carried on during the year 1903 and by far the greater part of the alkali removed. In 1904 crop tests on those portions of the land considered more fully reclaimed were valued at \$230. (See Pl. IV.) Flooding was considered necessary on some portions of the tract which still showed the presence of alkali. Late in the fall of 1904 the greater part of the tract was seeded to alfalfa, and in the early spring of the past year this had made a fine growth and the appearance of the entire tract was favorably commented upon by all those who had watched the course of the experiment. The crop returns for 1905 were approximately \$300.

Early in the summer of 1903 the Bureau selected a tract of 20 acres for a demonstration experiment at North Yakima, Wash. This tract of land is situated about 3 miles south of the town, and at the time of the selection was covered with a heavy growth of greasewood and salt grass. It is situated along Wide Hollow Creek, in a section where many fine farms have been ruined by the accumulation of seepage water and black alkali. The soil is a fine sandy loam characteristic of the volcanic ash soils of the Yakima Valley. Flooding was carried on during a portion of 1903 and again in 1904. Late in the fall of 1904 wheat was sown on the entire tract. This made a fine start, but by the spring of 1905 there were some spots that showed the presence of alkali in sufficient quantities to prevent the growth of a good crop. More than half the tract, however, produced a heavy growth of wheat, which reached in some cases a height of 6 feet. This was cut green for hay and produced a crop valued at \$160. Flooding was carried on during the past season, as it was evident that some places still remained where there was a considerable quantity of alkali. During the past fall the land was prepared and seeded to alfalfa, with wheat as a nurse crop. While it is yet too early to predict the outcome for this tract there will probably be some small places that will require further attention, as it seems to be very difficult to leach all the black alkali from soils of this character.

Early in 1904 another tract was located near Tempe, Ariz., in the Salt River Valley. During the year 1904 water was available only for flooding purposes a few months of the entire year. By far the greater amount of alkali, however, was leached from the soil during these months and test crops were started. The winter of 1905 was a remarkable one in this valley on account of the very heavy precipitation, and though the crops had made a fine start they were badly damaged by the very heavy rainfall. At the present time the alkali has been practically all leached from the soil and the greater part of the tract is seeded to alfalfa and barley, which give promise of a fine stand.

During the same year a fifth tract was installed at Billings, Mont., in the Yellowstone Valley. Alkali has increased very rapidly in this valley until at the present time it is a serious factor in the successful cultivation of much of the irrigated land. A tract of 20 acres about one-half mile west of the town of Billings was selected for demonstration. One or two unsuccessful attempts were made to cultivate the land of this tract about twenty years ago. Since that time no further attempts have been made to produce crops upon it. When selected by the Bureau it was covered with a meager growth of greasewood and salt grass, while heavy incrustations of alkali covered a large portion of the field. Much of the soil consists of a heavy adobelike soil characteristic of the valley and locally known as "gumbo." The alkali in this valley is somewhat unique, inasmuch as it consists almost

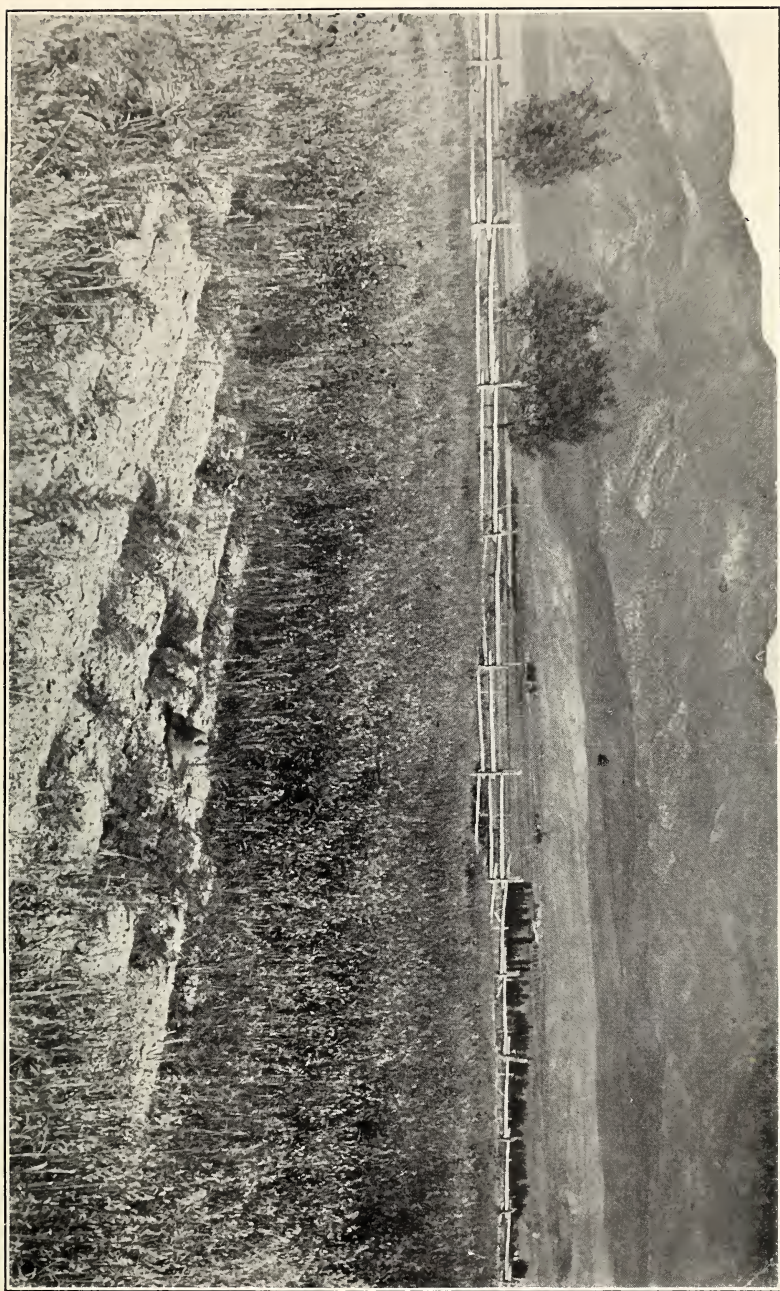
entirely of sodium sulphate. The installation of the drainage system was completed too late to allow any flooding operations to be carried on during 1904, but during the past year the entire tract was kept submerged for a period of several months. In addition to this, heavy rains during the early spring months of 1905 greatly assisted in leaching the alkali from the soil. Tests made during the summer of 1904 showed more than 1 per cent of alkali present in the soil to a depth of 4 feet, by far the greater amount occurring in the surface foot of soil. Tests made in the fall of 1905 showed that nearly all of the alkali had been leached from the first and second foot and comparatively small quantities remained in the third and fourth foot. A test crop will be sown as early as weather conditions will permit to make a practical determination of the extent to which reclamation has actually progressed.

EXPERIENCE GAINED FROM DEMONSTRATION EXPERIMENTS.

From the results on these five tracts it is seen that by carefully leveling the surface and by installing an adequate underdrainage system systematic flooding for one year is able to remove by far the greater proportion of soluble salts from soils containing even excessive quantities. As has been mentioned, the underlying principles of this method of alkali reclamation are simple enough, but there are certain difficulties in carrying the work to completion. In order to facilitate the work, it will be found advisable thoroughly to level the land before beginning operations. High spots that can only with difficulty be covered with water tend to hold and accumulate alkali, as already explained.

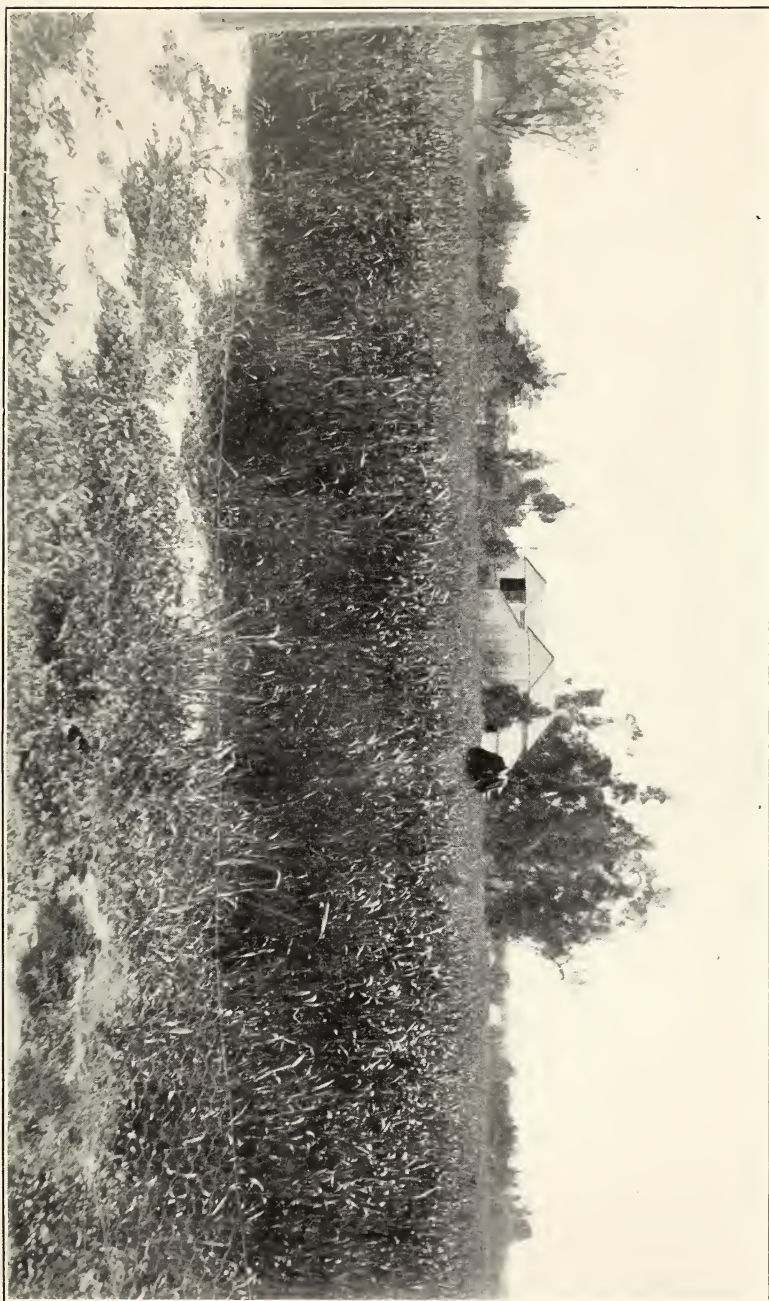
To provide an adequate drainage system, while the first essential step, will not of itself reclaim soils containing excessive quantities of alkali. The installation of a drainage system may effectually check the further accumulation of alkali, but it is only when abundant supplies of water are added that the soluble salts are leached downward through the soils and carried away by the drains. During the progress of flooding the tilth of the soil will perhaps be destroyed, the soil may become water-logged, and other bad results may follow. This will be especially the case if the soil is of such a character as to be easily damaged by repeated flooding.

At Salt Lake City, Utah; and at Tempe, Ariz., it was found that the soil in places plainly showed the effects of flooding. At the former station the soil is a silty loam that must be handled carefully at all times. It has a tendency to bake, forming a hard crust. In 1904, when the first crop test was made, most of the grain sprouted nicely, but examination showed the young seedlings curled and doubled, unable to break through the hard, baked surface. The first crop was not harvested, but plowed under to improve the tilth of the soil. At



SMALL ALKALI SPOT REMAINING IN A FIELD RECLAIMED BY IRRIGATION IN THE SEVIER VALLEY, UTAH.

Before reclamation no cultivated crop could be grown.



WHEAT CROP ON RECLAIMED ALKALI LAND NEAR FRESNO, CAL.

Reclamation has been accomplished in one year by flooding combined with underdrainage.

Tempe, also, it was deemed advisable to apply manure to those places where the soil had been put in bad physical condition. In many cases, especially with heavy soils, cultivation and turning under the first crops will often be necessary to restore the soil to a good state of tilth.

POSSIBLE INJURY TO THE LAND BY CONSTANT FLOODING.

Some have urged that flooding not only water-logs the soil and destroys the tilth, but also washes away the supplies of available mineral plant food. It is true that other mineral salts besides those injurious to crops may be leached from the soil, but the store of plant food in about all classes of soils is so great that no fear need be entertained that as soon as the alkali content is leached away the crop will suffer for lack of sufficient mineral nourishment. The mineral constituents entering into the composition of the crop are largely absorbed by the soil grains, and while the more readily soluble portion of these constituents might be leached away the soil would soon readjust itself, so that it would furnish all the essential mineral ingredients needed by the growing crops. Reclaimed alkali soils put in good condition as regards tilth and ventilation will be found as productive as those on which no flooding is necessary.

On certain soils it is a difficult matter to hold the water on the land, especially if the land has considerable fall. This has been found to be the case at North Yakima, Wash. On this tract the fall is approximately 1 foot in 100 feet, and with the light ashy soils derived from volcanic débris the dikes or levees surrounding the small plots of land have repeatedly broken during flooding operations. Banks $2\frac{1}{2}$ feet high and 3 feet wide at the base, when water was turned against them, at first acted almost like so many piles of sugar or salt. Even after they have been tamped and saturated many times the banks must be carefully watched to guard against breaking. Some farmers in the Yakima Valley who have attempted to hold water on their soils have given up in despair after a few disastrous breaks, which caused deep trenches to be cut across the fields they were flooding. By patrolling the banks the danger from these breaks is lessened, but this question must be considered in any attempt at reclaiming sloping fields with the light, porous volcanic ash soils found in the Northwest.

EFFECT OF HARDPAN ON ALKALI RECLAMATION.

An obstacle seriously retarding reclamation by any method that involves leaching the alkali downward is the presence of hardpan. Bands of more or less firmly cemented hardpan occur in almost all arid soils and have been frequently likened to the clay subsoils usually found in countries of abundant rainfall. Hardpan in many instances consists of a thin layer of sandy, gravelly material cemented together by calcium carbonate, iron compounds, or other cementing sub-

stances. Oftentimes upon the application of water this softens and no longer offers any resistance to the ready downward percolation of water. This is especially the case with a calcareous hardpan. The ferruginous hardpan softens little, if any, upon coming in contact with water. In some districts calcareous hardpan may extend a foot from the surface to a depth of several feet, forming a firm, continuous mass approaching in character a somewhat thick bed of limestone, so compact that it can only be broken by picks or heavy iron digging bars. Such layers or sheets of hardpan not only retard the percolation of water, but also greatly hinder the growth of deep-rooted crops and trees of all kinds.

In areas where such beds of hardpan occur it is to be doubted if it is advisable even to attempt to reclaim alkali soils. With the hardpan a foot or two from the surface the alkali can be leached to this depth, but probably no farther, on account of the slowness with which the water moves downward through the layers of hardpan. With the alkali at this slight depth, under favorable conditions it will rise slowly or rapidly to the surface, depending on the rate of evaporation of the soil moisture. Just such difficulties have been experienced on small spots in the reclamation tract near Fresno, Cal. Certain portions of the tract are underlain at a shallow depth by formidable beds of compact hardpan. The soil overlying this hardpan was freed from alkali by flooding, so that crops could be grown, but subsequent examination showed the alkali lodged in the upper layers of hardpan. Cultivation and cropping of the reclaimed soil above the hardpan prevented the rise of the alkali, but such treatment was necessary to prevent it from again accumulating at or near the surface. Breaking the hardpan at frequent intervals or open ditches instead of covered drain tiles would probably assist in allowing the water to penetrate more freely through this obstruction and consequently accelerate the final reclamation of lands with layers of hardpan a few inches in thickness. When the hardpan is within a foot of the surface and several feet thick, freeing the soil of alkali by leaching becomes of more doubtful application, if indeed it can succeed at all.

In this same connection it seems advisable to speak of the absorption of soils. Certain soils, especially clay soils, have a high absorption capacity for all kinds of soluble mineral matter. On such soils the first few floodings will leach away the excess of alkali salts, but beyond a certain point flooding will accomplish little toward removing the remainder, which is tenaciously held by the soil grains. In case of black alkali the portion absorbed and held by the soil may be sufficient to prevent the growth of crops. Just how far this factor enters into the successful reclamation of black-alkali soils is now being investigated in the laboratories of the Bureau of soils.

In reclaiming small tracts of alkali land in the midst of districts where the seepage waters move rapidly through the porous sandy soils, adequate provision must be made for the removal of the great quantities of water pouring in from all sides. If the drainage of the entire district were provided for, it becomes comparatively simple to install a drainage system that will remove the water necessary to leach away the alkali salts. If no regional drainage has been undertaken, the drainage system must be of such capacity as to carry away not only the excess of water applied at the surface and leaching downward through the soil, but that quantity that infiltrates from adjacent fields surrounding the particular tract of land being treated. At Fresno the Bureau has found it advisable to considerably enlarge the original drainage system for this very reason. The tract is located in a district where at certain months the ground water rises to within a few feet of the surface. To prevent the ground water from rising above a height of 3 or 4 feet it was necessary to lay lines of tile of larger dimensions and increase the water-wheel pump to three times its former capacity.

CLOGGING OF THE DRAINS.

The question of keeping the tiles free from silt and roots must be considered if the drainage system consists of drain tiles. Since drain tiles have been proved by many years of experience to be the most economical drainage implement, their use is to be recommended. Open drains are equally effective, and in Egypt large areas of alkali land have been reclaimed by surface flooding and drainage systems consisting of open ditches. Open ditches are cheaper, equally effective, and in districts where drain-tiles are to be had only at exorbitant prices may be used to good advantage instead of tiles or box or board drains. In sandy soils that do not stand well in bank open ditches will take up much valuable space and must be frequently cleaned to be effective. For a drainage system of tiles to be effective, the tiles must be kept free from all obstruction, such as roots and sand or silt. Some soils, especially those that carry large quantities of fine micaceous silt, enter through the joints of the tiles almost as readily as water. Heavy clay soils when firmly settled over the lines of tile cause little trouble, and the tiles have to be cleaned only at long intervals or not at all. At Fresno, Cal., the Bureau has had difficulty in keeping the tiles open and effective at all times. In the newly installed drainage system at that point steel-wire cables have been placed in all tiles. To these cables wire brushes may be attached and drawn through as often as the occasion demands. On two large ranches in the Fresno district the same difficulty has been experienced. It is now several years since the drainage systems were installed, and

it is still necessary to draw wire brushes through the tiles twice each year to free them from silt and roots. By this method the systems have been kept in perfect order, and the ground water is maintained at the level of the tiles. Where it is believed no especial trouble need be feared from silt, in extra long lines of tile, occasional silt boxes may be sunk below the level of the tiles. These serve as a check on the manner in which the tiles are working and can be cleaned as often as required. They may also be used to serve as standpipes to introduce water under pressure into lines of tile that may become clogged by local obstructions. They can be cheaply placed in position at the time of installing the drainage system.

DEPTH AND DISTANCE APART FOR DRAINS.

In considering the depth of the drainage system it should be remembered that the deeper the drains the greater the depth of alkali-free soil obtained after the land is reclaimed. This is important, as is also the depth to the water table, which is also lowered by the drainage system. These factors should be taken into consideration, always keeping in mind the increased cost of placing the drains at greater depth. For each foot of earth removed the cost of digging ditches greatly increases, so that beyond certain depths the question resolves itself into whether the farmer can afford the extra cost. With cheap labor it will be found more economical to make a few deep ditches than many shallow ones. The deep ditches not only lower the water table to a greater depth, but also drain a wider area of soil, hence fewer drains are needed. With deep drains the chances for future rise of alkali are reduced. In certain classes of soils capillary action lifts water from a depth of several feet. Obviously if the depth of reclaimed soil is considerable, and even below the depth from which capillary water will rise, there will be practically no danger from a further accumulation of the alkali washed down to the level of the drains. In most cases it will be difficult to install a drainage system below this depth, but each additional foot of reclaimed soil makes a second alkali accumulation more improbable. In practice it is not advisable to place drains less than 3 feet deep, and depths of 4 or 5 feet or more give much better results.

The distance apart at which drains should be placed depends largely on the character of the soil. In heavy soils rapid reclamation may be accomplished with drains 100 to 150 feet apart. In porous sandy soils the distance may be greater, intervals of 250 to 300 feet in many cases answering the purpose. The less the interval between drains the more rapid can reclamation be carried on, but the distances given above are conservative.

COST OF RECLAIMING LANDS BY FLOODING AND DRAINAGE.

As to the cost of carrying on such reclamation, it has been found to depend on the local conditions in each area. While in the central portion of the United States all sizes of drain tile are sold at reasonable prices, this is not the case in the West. Factories making such material are few and inclined to sell their product at a little less than such material could be shipped from eastern points. At the present time such prices are almost prohibitive. The demand for drain tile has been so limited that there is, as a matter of fact, very little inducement for people to engage in this business, and the farmer undertaking the drainage of his land is at the mercy of the few established manufactories. Even considering the exorbitant prices at which the farmer must purchase his tile, it is still possible in the greater number of western districts to provide an adequate drainage system for small tracts of land at an average cost of from \$15 to \$25 an acre. Drains consisting of boards are also effective, but they are not so permanent as drain tile and in many localities will be found nearly as expensive in the first instance.

To reclaim lands containing any considerable amount of alkali will cost from \$30 to \$50 an acre, including the cost of installing drains, leveling the land, and constructing necessary levees and dikes, as well as the cost of flooding. The item of leveling has been estimated at from \$5 to \$15, which would cheapen the cost of reclamation just so much in case the land had previously been leveled.

This method of reclamation has been used successfully in Egypt, as well as at many places in the United States, and, with the possible exception of areas underlain with hardpan, there can be no doubt of its feasibility in the irrigated districts of this or any other country.

CONCLUSION.

In the foregoing pages it has been shown that arid soils are rich in water-soluble mineral matter. In small quantities these mineral salts are probably beneficial to plants, but excessive quantities prevent the growth of valuable crops. Alkali salts move within soils only in the presence of water or soil moisture, and injurious accumulations are usually the result of overirrigation or seepage from canals, with no provision for removing the water in excess of that needed by growing crops. Certain precautions greatly retard, if not altogether eliminate, injurious accumulations of alkali, but for areas already ruined by alkali salts the problem becomes more serious. Several methods are available for removing or counteracting the alkali. Each method under certain conditions can be relied upon to give satisfactory results, but the landowner should carefully study all phases of the question before deciding which method is best adapted to his needs. He

should determine the value of his land in its present condition and its producing value, as well as market value when once reclaimed. It is poor business judgment to expend more money and labor to reclaim land than the same land will be worth after it is reclaimed. It is likewise short-sighted policy to abandon valuable land that can again be made productive by the expenditure of small sums of money or by the farmer's own well-directed efforts.

As the need of drainage is more thoroughly appreciated, measures will be enacted that will bring relief to districts suffering from seepage waters and alkali. In speaking of alkali in Colorado, Dr. W. P. Headden, of the Colorado agricultural experiment station, states that "the only question of alkali that we have resolves itself into one of drainage, and beyond this there is no alkali question." This need of drainage is becoming more imperative as conditions grow worse, and in some districts each succeeding year marks a step forward in this direction. Sentiment is being aroused on all sides and the formation of drainage districts controlled by just laws is under way in a few irrigation centers. With the drainage of those districts badly damaged by seepage and alkali provided for, the control of alkali becomes a problem easy of solution. Until such time real progress can be made only by the individual efforts of farmers or groups of farmers.



